DUAL-SCALE MODEL FOR DELAMINATION OF COMPOSITES WITH DIFFERENT FIBER ORIENTATIONS AT INTERFACE

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ABSTRACT

Improved design of composite parts relies on the knowledge of the mechanical response of the material to different loading conditions. In particular, to increase the resistance to delamination, it is important to understand the behavior of ply interfaces with a specific ply orientation. In the literature, there is no consensus on the effect of fiber orientation at the delimitating interface on the interlaminar fracture toughness [1-2]. This can be attributed to a) undesired damage mechanisms during delamination testing, b) dissimilar specimen geometry (thickness, lay-up), and c) accuracy of the in-situ characterization techniques for real-time measurement of delamination.

Varandas et al. [3] proposed a numerical method to investigate this effect via modeling a Double Cantilever Beam (DCB) specimen with a refined region around the delamination tip. Investigating two different interfaces, 0°/0° and 90°/90°, they noted that crack propagation was stable in the former, while migrated to the adjacent interfaces in the latter case. They used downscaled dimensions for the specimen, compared to the standard suggestion, and did not calculate fracture toughness values.

In the current study, a numerical model of a DCB test is developed that is capable of analyzing the resistance to delamination for different fiber orientations at the interface. Delamination interacts with the microstructure during propagation and can involve other damage mechanisms at the microscale. Thus, a dual-scale methodology is proposed, which includes a refined region with microscale features, i.e. individual fibers inside the matrix, in the vicinity of the delamination tip as well as the macroscopic features of the DCB specimen. With this formulation, important findings can be achieved regarding the crack initiation, which is not straightforward to be observed experimentally due to its small scale.

Two different fiber orientations at the delamination interface were used as study cases: 0°/0° and 90°/90°. The specimen dimensions and the size of the refined region were defined such that a balance was hold between the accuracy of the stress distribution in the region of interest and the computational cost. A random distribution of fibers was generated inside the refined region, using Melro algorithm [4], which consisted of parts of the two delaminating plies. Two boundary conditions were considered: 1) *free edge* to represent the real boundary conditions in a DCB test with standard width and 2) *fixed edge* to compensate for the reduction in width.

The dual-scale model with the refined region was compared to a single-scale model with homogenized properties to investigate the influence of the heterogeneity on the resulting stress-strain field. This comparison allowed to understand the importance of including the refined region at the crack tip to simulate, with sufficient accuracy, the various mechanisms occurring at the microscale during delamination. The results for the linear analysis revealed that, even if the specimen is very narrow

(~15 times smaller with regard to the standard width), the free edge boundary condition provide a reasonable stress state as in the internal region of a DCB specimen. The results for the non-linear analysis showed, for both interlaminar interfaces, a crack path in agreement with that reported in the literature (Figure 1). In addition, with the present model it was possible to estimate the fracture toughness at the very beginning of the crack propagation for the two interlaminar interfaces.

With further improvements, such as including fiber/matrix debonding and refining the mesh, this numerical model allows materials scientists to study the effect of different fiber orientations at the interface on the macroscale properties like interlaminar fracture toughness, accounting for the microscale damage mechanisms. In addition, this model allows to investigate the effect of the proposed toughening mechanisms in the literature, such as nano-engineering and particle toughening of the interface, which are not easy to be measured experimentally.

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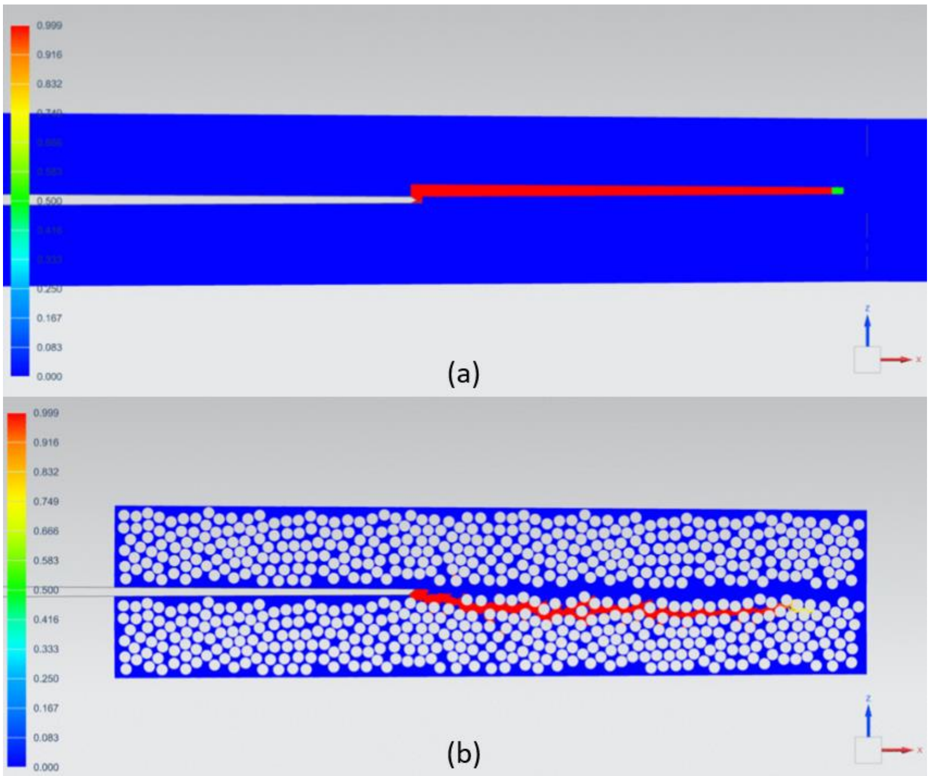

Figure 1: Simulation of delamination propagation in the refined region at the (a) 0°/0° and (b) 90°/90° interfaces. The crack stays at the middle interface in the former, while it deviates in the latter case.

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